Report# CTI/DAAK7089/002

Comprehensive Technologies International

Belvoir RD&E Center

US ARMY TROSCOM

CHEMICALS AND STRUCTURAL FOAMS TO NEUTRALIZE OR DEFEAT ANTI-PERSONNEL MINES

TECHNICAL REPORT
Contract# DAAK70-89-D-0054

PREPARED BY
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22021

October 1990

PREPARED FOR

Belvoir Research, Development and Engineering Center
(BRDEC)
Countermine Systems Directorate
Fort Belvoir, Virginia
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EXECUTIVE SUMMARY

This report provides a market survey, study and analysis of chemical and structural foam products to determine if current technology could be used to defeat/neutralize anti-personnel mines.

The study and analysis involved sixty-four companies. The market surveillance started with an announcement in the Commerce Business Daily to identify potential suppliers of chemical or foam products. This was augmented with a literature search. A formal survey was conducted and site visits were made to government and commercial facilities to gather more information on the most promising commercial products. A structured decision analysis was performed on the most suitable product and delivery systems. Recommendations were made based on a number of recognized criteria. Additional information (considered proprietary) pertaining to this study is contained in a Limited (Government Agencies Only) Distribution Appendix.

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PREFACE

The specific foam product and delivery system data, concepts, numerical information, photographs, and line drawings contained in this report were provided by the five companies involved in the survey and final analysis. Proprietary information has been withheld from this report. It is available to authorized readers in a Limited (Government Agencies Only) Distribution Appendix.

Guidance in the preparation of this report was received from Science Applications International Corporation (SAIC) and Belvoir Research Development and Engineering Center (BRDEC). Their assistance and comments are appreciated.

CHEMICALS AND STRUCTURAL FOAMS TO NEUTRALIZE OR DEFEAT ANTI-PERSONNEL MINES

INTRODUCTION

This technical report has been prepared as required for contract #DAAK70-89-D-0054, titled "The Use of Chemicals or Structural Foams to Neutralize or Defeat Anti-personnel Mines". The objectives of the contract tasks are to:

a) Conduct a market surveillance of available chemicals and/or structural foams with their dispensing systems for the neutralization of anti-personnel mines.
b) Conduct a literature search and make site visits to government and commercial facilities to collect technical data pertaining to use of chemicals/structural foams to neutralize mines.
c) Develop, analyze, and recommend at least two delivery systems and employment concepts.
d) Submit a Study Gist and Final Technical Report.

This report presents the methods used by Comprehensive Technologies International, Inc. (CTI) to achieve the stated objectives and the results achieved during the study effort.

Prior to conducting the market survey, goals and objectives for a desirable candidate had to be defined and some assumptions had to be made. First, a well defined background description of the Threat was needed. The Threat was assumed to have the capability to employ a variety of mines in large quantities and, through the use of minefields, restrict the mobility of an attacker or counterattacker. This concept of the Threat was later changed and defined to specifically reflect a low intensity conflict environment. The Threat was defined as one of sparsely placed mines or booby traps.

The initial area of countermeasures to be explored was "the use of chemicals or foams as candidate explosive and nonexplosive agents for dismounted breaching operations against anti-personnel mines". The candidate explosive agents were later eliminated from consideration by Belvoir Research, Development, and Engineering Center (BRDEC).

CTI identified the product characteristics needed to meet the Army's requirements. Initial specification and performance characteristics given to CTI by BRDEC were:

a) A chemical reaction to neutralize the mine within five minutes after application. In the case of using structural foam, a less than five minute cure time is needed.
b) Structural foam candidates need to contain enough compressive strength to support the weight of a soldier passing over the foam after it has set.
c) The delivery system is to be small, compact, and need little accessory equipment. Its weight is not to exceed three pounds to outfit a small group of individuals engaged in a low intensity conflict.
d) Chemicals or structural foams are to be used to defeat a variety of anti-personnel mines (e.g. pressure plate, trip wire, bounding mines, booby traps).
e) Chemicals or structural foams are to be used in a variety of likely operating environments (e.g. hot and cold temperatures; dirt, clay, or sandy soil; humid, damp, or very dry conditions).
f) Because of the low intensity and stealth environment, the requirement of a non-explosive, non-signature reaction between the neutralizing agent and the mine will be needed.

Besides these six general specifications, the following assumptions were proposed and approved by BRDEC, and were used to achieve the study objectives.

a) Cure time for the different product candidates is to be evaluated at room temperature. Product modifications may be needed to meet other temperature requirements at a later time. Comparisons of cure times are to be done at 75 degrees, $\pm$ 2 degrees Fahrenheit.
b) Target mines in question have been located and identified. This study does not involve evaluating systems which identify and locate mines.
c) Candidates surveyed would be limited to existing capabilities of chemicals or structural foams. Research and development of new chemical or structural foams would not be easy to assess

against existing products. Proposed systems by vendors will be analyzed separately for further consideration. The delivery systems of some candidates may need alterations, but unmodified readily-available systems are preferred for this analysis.

Figure 1 illustrates the concept of using foam to neutralize anti-personnel mines. The mine is partially buried, and the foam would cover the exposed sensors which trigger detonation if disturbed.

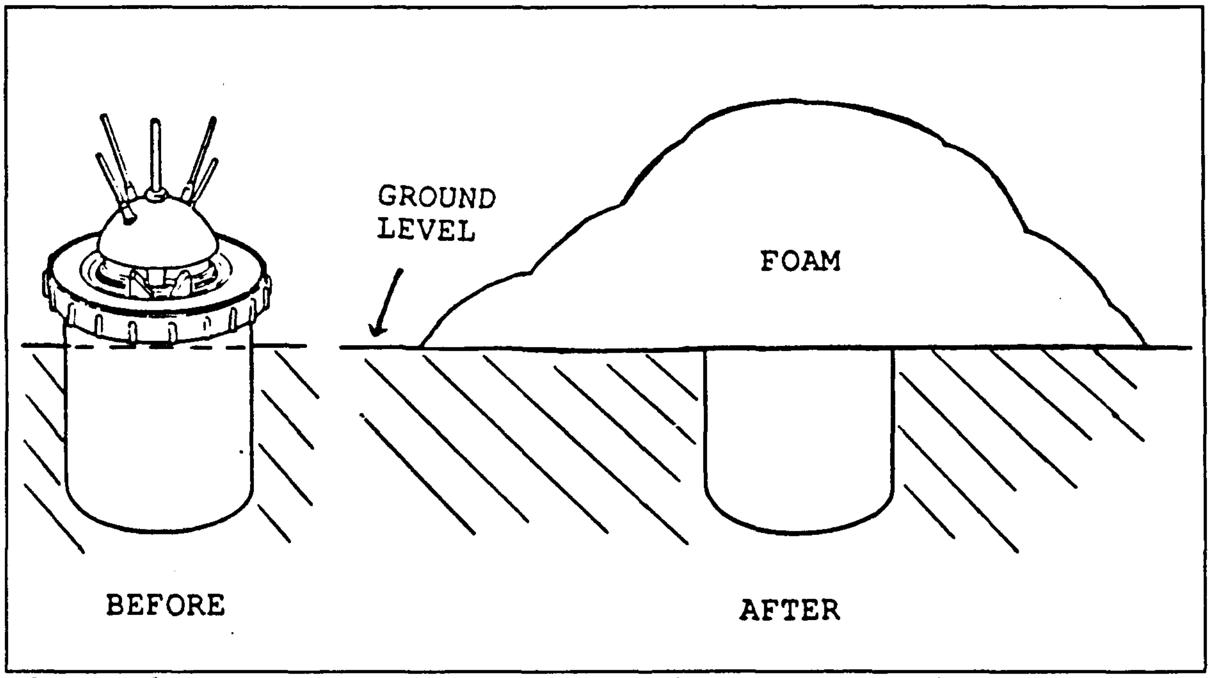


Figure 1. Foam Applied To An Anti-Personnel Mine

STUDY DETAILS

MARKET SURVEILLANCE

The market surveillance was conducted for one purpose. The purpose was to gather information and data on existing chemical and foam technologies which could be used in a military application to neutralize the threat of anti-personnel mines. This would be accomplished by deploying a bridging mechanism composed of structural foam, or by a reaction using chemicals to immobilize trigger mechanisms.

The market surveillance consisted of two main thrusts. First, a Commerce Business Daily (CBD) Announcement was developed by CTI and approved for publishing by BRDEC. The announcement was published on April 11, 1990. The nine company responses were evaluated and three companies were retained as potential candidates for further consideration. Two of the six eliminated companies were dropped because their means to defeat the mines consisted of using explosive agents. Three other eliminated companies did not have an existing foam or chemical and could not present an immediate concept for development of a valid candidate. The last company chose not to respond to the survey questionnaire sent at a later date.

The second part of the market survey identified candidates by researching chemical and foam companies listed in chemical and plastic periodicals, the Desk-Top Data Book (foams edition 2), and the Thomas Register. A total of thirty-six chemical companies were selected for further investigation. A complete list of these companies is shown in Table 1 at the end of this section. Large and small companies are represented on the list. The first group of 15 consisted of the largest companies. After contacting these companies by telephone, it was discovered that companies of this size generally deal in bulk raw materials. These companies had not developed ready-to-use systems for an application which could fit the Army's needs. The second group of 14 medium-sized companies did deal with chemical products, but did not have a product line suitable for mine countermeasure capabilities and were not interested in developing such a product. The third group covered small companies. Five of these seven companies were no longer in business. The other two did handle specialized products but both stated they were too small to spend any time or resources developing a suitable anti-mine product. These findings provided no chemical companies to include in the

study as candidates.

Besides the chemical companies surveyed, foam companies were also identified as potential company candidates. These companies were broken down by a different means. A complete list of these companies is shown in Table 2 at the end of this section. The first group of 17 create foam products using heavy machinery and moldings in a factory setting. They mass produce foam products in specific shapes and designs. These particular foams could yield an end product which could serve as a countermeasures for mines, but the systems would be too large for field deployment. In some cases, there are stringent and controlled requirements for producing these foams. The other two companies have more portable foam systems potentially well suited to the BRDEC application.

In all, sixty-four companies were included in the market survey. Fifty-eight of the companies received a survey questionnaire. The remaining six that did not receive a questionnaire had initially responded to the CBD announcement, but did not have a product line suitable to meet mission requirements. After the screening afforded by the questionnaire, an in-depth telephone conversation determined more about the companies' products and the product capabilities. Five companies eventually emerged as legitimate candidates for continued evaluation.

To ensure all avenues were explored during this phase of the study, eight local area hardware and building material suppliers were visited to identify commercial off-the-shelf products. Some structural foam products were available at these facilities, but the cure times for these products were far too long. Eight hours was the average. Conclusions drawn from the market survey are:

a) No chemical products reviewed in the survey could be used for mine countermeasures.
b) All the structural foam candidates surveyed, with one exception, have a two component system, which could present some packaging problems for lightweight systems.
c) Current industrial applications of structural foams are not suitable for the field. Portable, lightweight structural foam system requirements greatly reduced the field of candidates.

TABLE 1. Chemical Companies Surveyed

Company Name
Allied-Signal, Inc.
ARISTECH Chemical Corporation
BASF Chemicals Division
Carbose Corporation
Charles B. Edwards & Co.
CHEM Design Corporation
CHEMSERVE Corporation
Climax Performance Materials Corporation
Degussa Corporation
DOW Chemical
Dunbar Sales & Manufacturing
DuPont
FERRO - Bedford Chemical Division
Flameout International, Inc.
FMC Corporation
Hooker Chemicals & Plastics
Kali-Chemie Corporation
LPS Laboratories, Inc.
Monsanto Chemicals
Olin Urethane Systems
Parker & Amchem
Percy Harms Corporation
Raperswill/Rapco, Inc.
ROHM & HAAS
Shell Chemical Company
SHEREX Chemical Company
Statpak International Traders, Ltd.
Union Carbide Corporation
Uniroyal
UNOCAL Chemicals Division
Upjohn Company
VELCO Enterprises, Ltd.
VersaPak
Vinings Industries
Whitmire Research Labs
WITCO Corporation

TABLE 2. Foam/Plastics Companies Surveyed

Company Name
Amoco Engineered Plastics
Canadian Insulock Corporation
Comcast Urethane
DuPont Thermoplastics
Foam Enterprises, Inc.
Foam Molding of Arkansas
Foss Foam
General Electric Plastics
Innovative Plastics Corporation
Insta-Foam Products
Magnolia Plastics, Inc.
Midgard Inc. of Florida
North American Reiss Corporation-
Kenkor Molding Division
Kentron Extrusion Division
NOVAGARD Foam Seal Division
Pelafoam, Inc.
PTA Corporation
Reliable Plastics, Inc.
ROMARC Corporation
Structural Foam Plastics, Inc.
Other Companies
ARVIN Calspan Corporation
Ensign-Bickford Company
Foster-Miller, Inc.
Hauser Laboratories, Inc
Hughes Aircraft
Martin Marietta
MREL
S-Cubed

LITERATURE SEARCH

The objective of the literature search was to obtain background knowledge in the areas of chemical and foam technology, anti-personnel mine warfare, and similar studies performed on chemicals or structural foams and their properties and strengths.

The literature search was performed concurrently with the market surveillance. CTI analyzed past studies dealing with foams and their properties, information on anti-personnel mines, and on existing products with unique qualities which could be adapted to countermine warfare. Resources and their use in this study are as follows;

a) Local public and university libraries, and Fort Belvoir and the Pentagon library were used to gather background information on polymers, plastics, chemicals, structural foams, rapidly solidifying resins, and various anti-personnel mines. Pertinent subject matter books and periodicals were examined.

b) Defense Technical Information Center (DTIC) and National Technical Information Service (NTIS) were used to gather specific studies and reports which involved plastics, structural foams, and rapidly solidifying resins in various types of environments, surveys, and tests.

c) National Aeronautics and Space Administration (NASA) was used to investigate polymers which are currently being used in the rugged environment of the shuttle program.

d) National Institute of Standards and Technology (NIST) was used to research other documented studies of foams, chemicals, and resins.

e) Janes Military Vehicles and Ground Support Equipment was used in researching Eastern Bloc and Third World anti-personnel mines.

f) Army Field Manuals and Pamphlets were used for mine warfare and countermeasure concepts.

g) The Canadian Embassy Library was used to locate a potential candidate which is based near Vancouver, British Columbia.

Table 3 lists sources used in the study. Further specific information on publications can be obtained from the bibliography at end of this report.

TABLE 3. Research Sources

AGENCIES
Defense Technical Information Center
National Technical Information Service
Government Printing Office
National Aeronautics & Space Administration
National Institute of Standards & Technology
Fort Belvoir Van Noy Library
BRDEC Technical Library
Pentagon Library
Local University Libraries
Local Public Libraries
Canadian Embassy Library

PUBLICATIONS
Government Reports Annual Index
Index of Army Manuals & Publications (DA PAM 25-30)
Thomas Registers
Scientific & Engineering Periodicals
Published Technical Notes & Abstracts
Reader's Guide to Periodical Literature
Janes Military Vehicles and Ground Support Equipment

After receiving the responses to the CBD advertisement, BRDEC and CTI held three meetings in the following six weeks. The meetings covered areas such as determining types of studies to order from publishing agencies and establishing property characteristics which would be ideal for product candidates. The product characteristics were needed to develop a survey questionnaire which would be mailed to the chemical and structural foam community. Appendix B contains the complete survey questionnaire used in researching the market.

CTI developed the survey questionnaire, divided into four major parts. The four sections were Deployment , Logistical, Environmental, and General characteristics. After development of the survey questionnaire, BRDEC was asked to review and approve the contents to ensure that the desired information would be addressed. The questionnaire was then mailed to the thirty-eight chemical companies, the seventeen structural foam companies, and to the companies which responded to the original CBD announcement and could meet the mission requirements. These fifty-eight companies were initially given 23 calendar days to respond to the questionnaire (later the time allowed was extended two more weeks).

In analyzing responses to the questionnaire, several factors were noted. The reasons for companies not responding varied and are as follows; the chemical companies do not deal with explosive agents (most of their business is in the agricultural products line), some foam companies have worked uniquely in the construction or insulation business, other foam companies stated their products are used in a factory oriented environment, and still other companies did not wish to invest time or resources with Department of Defense business due to the uncertainty of budget cutbacks. In all, only five companies of the original companies responded.

SITE VISITS

The objectives of conducting the site visits were to gain as much knowledge as possible about the candidate companies, their available products and developmental capabilities, their manufacturing capabilities, and other proven capabilities which could benefit mine countermeasures. From the five companies which responded positively, three were selected for site visits and the remaining two companies were invited to meet and present their company and product lines to BRDEC and CTI personnel at BRDEC. The site visits and the meetings were to further explore the candidate products and to clarify the specific characteristics prior to performing comparative analyses. The selection of the site visits was based on the nature of the candidates products as they exist today. In two cases the products themselves did not make it feasible for meeting at BRDEC. One of these two products is not entirely mobile, and the other product's delivery system is still in the infant stage of development. A third candidate simply could

not make such a trip on short notice. The five companies will be referred to as Companies A,B,C,D, and E. The Limited Distribution (Government Agencies Only) Appendix E (a separate document) contains the key to the companies.

Company A was selected as a candidate for a site visit due to the nature of the dispensing system. Their primary market is structural foam users, encompassing a variety of applications. The foam system itself is a two component system which is propelled by Carbon Dioxide (CO_2). The current configuration which Company A uses is three large cylindrical containers, two of which contain the components that, when mixed, produce the froth (structural foam). The third cylinder contains the CO_2 propellent which forces the mixing of the two components (see Appendix D for illustrations). Both of the component cylinders are attached to a rifle-like gun by hoses. The materials are forced through the hoses and into the hand held gun which controls the amount of foam desired. A modification to this system involves two smaller (2 gallon) cylinders which would be pressurized. The cylinders would be in a backpack configuration and be attached to the hand held gun by hoses, however the hoses would only be 3 feet or less in length.

Company B was selected as a candidate for a site visit due to their stage of development as pertaining to using structural foam to defeat anti-personnel mines. Demonstrations were performed using commercially available foams. The demonstrations used structural foam as a countermeasure against various simulated mines and booby traps. One simulation involved a trip wire mechanism which, when activated, would complete an electrical circuit and illuminate a lamp. The illuminated lamp signals the mine or booby trap detonating. The simulation was performed with and without the foam deployed over the mine. The foam successfully defeated the trip wire mine. Other simulations involved a syringe type of booby trap and various pressure sensitive mines. Each time the foam successfully defeated the simulated mine. Company B proposes a two component system which would be designed and formulated by them. They would also design the packaging of the system (see Appendix E). Another possibility Company B proposes is a development of a microencapsulated system, thus making a single component system for packaging purposes. This would simplify the delivery system, and produce a foam effective throughout wide temperature ranges.

Company C met with BRDEC and CTI personnel at Fort Belvoir. Their proposal is a two component urethane foam system. Currently their product comes in three sizes. For the Army's application, only the smallest size will be

evaluated. This system produces one cubic foot of foam, which subject matter experts at Fort Belvoir have stated as the volume needed to defeat a mine. The system consists of two aerosol cans packaged together which are connected and held by a pistol type grip (see Appendix D). This gripping mechanism has a trigger that would be squeezed to deploy the foam. One drawback was noted when dealing with pressurized products, especially ones using CFC based blowing agents (Freon); their performance is greatly affected in low temperatures (40 degrees Fahrenheit or lower). High temperatures also affect the structure of the final product. There is a risk of an inadvertent explosion with pressurized containers.

Company D met with BRDEC and CTI personnel at Fort Belvoir. Their proposed system is based on a similar program which had been funded in the past by Fort Belvoir. This program was based on the concept of a much larger scale application. The delivery system consists of two pressurized containers mounted on a backpack. Hoses are attached to the containers which attach to a hand-held extension arm. This extension, which is about six feet in length, is held out in front of the soldier and dispenses foam pads downward for the soldier to walk on. This system was initially designed so that a column of soldiers could walk through a minefield on the foam pads (see Appendix D). Company D did state that compacting the system would be difficult, but not entirely impossible.

The site visit to Company E involved several demonstrations of different foam products, the foam systems, and a tour of the research, development, and production facilities. Company E proposes a two component foam system (shown in Appendix D). This system is comprised of two liquid components which were designed to remain at about the same viscosity as water at nearly all temperatures. This system was specifically designed and tested for North Sea drilling operations. The demonstration of deploying this system showed how simple it is to operate. Each component was placed in a paper cup, filling the cup about halfway. The components were mixed by pouring the cups into each other 3-4 times. At this point the product was considered mixed, and after a delay of about 30 seconds, began foaming. Once it begins to foam, the contents are poured over the desired area.

The data collected from these five companies is thoroughly evaluated in the analysis phase. Their existing products, as well as any proposed systems, have been analyzed according to the Army requirements and preferences. This process is explained and presented in the next section.

ANALYSIS

INTRODUCTION

The literature search, market survey, product research, and site visits were completed before the analysis phase was initiated. Responses to the survey questionnaire, along with site visits to selected companies, provided product-specific information which was needed to begin detailed analysis of the candidates. The previously discussed objectives and requirements of the proposed Army application provided the basis for analyzing candidate products. The majority of the data analyzed was reported data, with additional observed data collected during site visits. Testing of the products by CTI was neither required nor practical at this stage, and therefore was not accomplished.

METHODOLOGY

The final list of criteria used in this analysis was determined by specifying what properties were essential in successfully defeating particular types of anti-personnel mines. The properties were determined by various subject-matter experts from BRDEC. The mines considered may be constructed of metal, plastic, etc., and have fuzes, detonators, or trip-wires of various types. Illustrations of the specific types of mines in the projected scenario for this analysis can be viewed in Appendix B. These are the types of mines which could be successfully neutralized using the proposed foam system. It should be noted that CTI has not tested the actual effectiveness or reliability of foam against these mines. The information in Appendix B is based on discussions with BRDEC.

Utility analysis was the method chosen to determine the best potential foam and delivery system. The field of decision analysis offers many techniques, but the analysis required for this project was deemed best-suited to utility theory methods. This is because utilities are used when the decision criteria must be based on more than just one factor, such as expected monetary value. There are many factors which must be systematically considered in this analysis. Utility is a measure of the total worth of a particular outcome, reflecting the decision makers' attitudes toward the whole collection of factors. Attitudes and preferences, as reflected in the weights assigned, are the subjective input to this process. The specific product data measures and alternatives provide the objective input.

The analysis was accomplished using Logical Decision (LD); a multiple-attribute decision analysis software package

which was reviewed by the project engineer. LD is particularly well-suited to this analysis because it has the ability to combine different units of measurement into one utility (measure of worth or desirability) function for weighting and comparison purposes. This study uses such diverse units of measurement as dollars, minutes, pounds, and percentages. LD permits a valid and accurate analysis without having to convert all measures to a common unit. LD also performs sensitivity analysis if the decision-makers decide to change the original weights they assigned to the measures. The resulting change in the final rankings will be computed by LD, and is useful for future comparisons and decisions. The formulas LD uses for different measures' utility calculations are shown in Appendix C. The product-specific data from the surveyed companies, and the preferences and weights provided by the BRDEC subject-matter experts were used as the analysis input to LD. These figures are presented in more detail in the following analysis discussion.

The initial analysis covered two separate areas - the foam products and the delivery (or dispensing) systems. The final analysis included both the type of foam product and the dispensing system used to apply the foam to the mine. This provides a complete system best suited to the mission. Figure 2 illustrates the structure of these first-level goals in LD. This shows the basic approach used for this analysis.

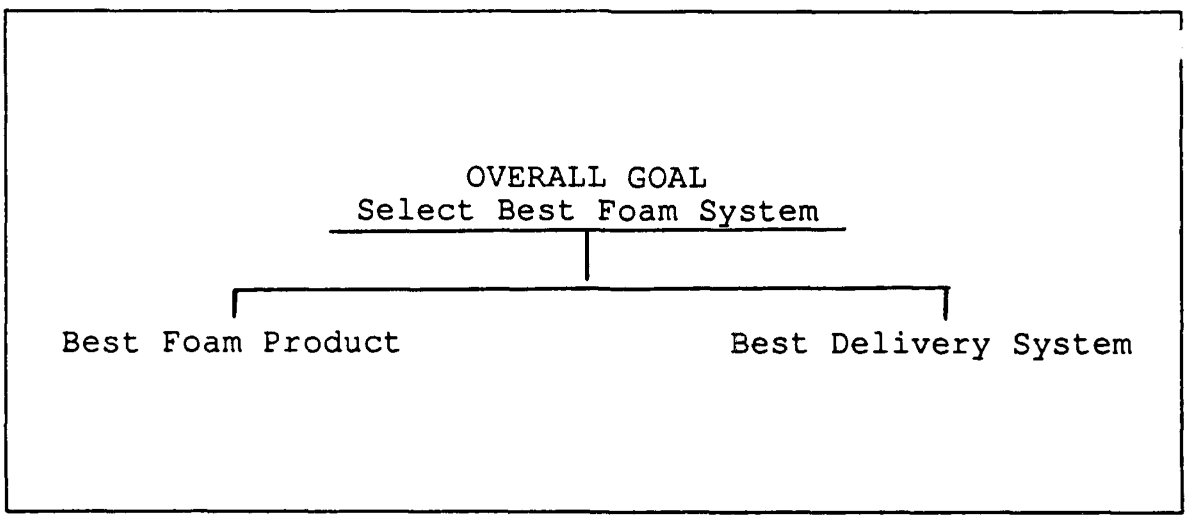


Figure 2. Initial LD Goal Structure

ANALYSIS OF FOAM PRODUCTS

Rigid polyurethane foam was the product all of the candidate companies recommended for neutralizing mines. No chemical candidates were proposed by the surveyed companies, and therefore none are included in this analysis. Some foam properties which initially were of concern and importance for this application proved to be similar or exactly the same for all foams. Specific characteristics found to be the same for all candidate foams are:

- Rigid polyurethane foam is made from two components. Component A is an isocyanate and component B is a polyol containing catalysts, surfactants, and (possibly) blowing agents. Ratios of the mixtures vary between products, and are generally considered to be company competitive in nature.
- Components display similar environmental and personnel hazardous properties. Suggested protective gear was not a concern because users in the field will already be properly outfitted. Typical field equipment includes gloves, heavy footwear, headgear, and possibly masks or face-coverings. Most companies recommended wearing gloves while dispensing the foam. Outdoor use ensures adequate ventilation.
- Foams remain effective practically indefinitely once deployed and hardened. The amount of time it takes for the cured foam to break down is far longer than this application requires, so this became an unimportant factor. The effects of long-term exposure of the foam to the elements was also determined by BRDEC to be insignificant.
- Compressive strength of foam is a function of density, and is relatively standard throughout the industry. Manufacturers can vary the interaction of these characteristics as required to obtain desired strengths.
- Foams bond well to almost any reasonably dry substrate including soil, sand, wood, and metal. Moist surfaces may alter density at the point of contact. This was not a major concern as long as required pounds per square inch (psi) and pounds per cubic foot (pcf) were maintained.

Some differences in properties among the candidate foams required further analyses and comparisons. Company E demonstrated a pour-in-place foam which is hydrophobic. Other companies make frothing or foam-in-place products which are hydrophilic and therefore have different characteristics. A major concern was the extreme sensitivity to temperature displayed by the standard foam formulations. The foam best

suited for Army field use should retain its qualities at a wide range of temperatures. According to some companies' personnel, the standard portable foam kits produced low-quality foam after storage at low temperatures (below 50 degrees F.). Another consideration, because of environmental concerns, was if the product needed a blowing agent to function. Some products are currently formulated with Freon or other blowing agents (Companies A and D), while others (Companies E and C) are chlorofluorocarbon (CFC)-free. This was not a major concern at this point in the project, and will be addressed by BRDEC at a later stage. During the analysis, differences such as these were considered for their importance to the countermine application.

The final criteria determined by BRDEC to be the most important were cure time, compressive strength, density, shelf life, and hazards. Cure time is the length of time it takes the foam to harden to the point where a person can step on it without detonating the mine underneath. The measurement for hazards associated with each product is taken from the National Fire Prevention Association (NFPA) rating on the Material Safety Data Sheet (MSDS) for each product. This is a combination of the ratings given to the product's health, fire, and reactivity (instability) characteristics. The hazard rating is normally assigned to Component A and Component B separately, and will be shown as such in the final analysis (with A and B each having a weight of 5). Table 4 shows the order of importance and the measures of performance for the criteria, with the most important at the top of the list. The priorities were determined by the weights assigned to each criterion by the BRDEC subject-matter experts based upon the project goals.

TABLE 4. Foam Product Evaluation Criteria

CRITERIA	WEIGHT	EVALUATED IN TERMS OF
Compressive strength	40	Pounds per square inch (psi)
Curing time	30	Minutes cure to support weight
Shelf life	10	Effective years in storage
Density	10	Pounds per cubic foot (pcf)
Hazards	10	NFPA rating from MSDS
Total	100	

ANALYSIS OF DELIVERY SYSTEMS

The delivery and dispensing systems proposed by the companies showed a great variety of characteristics. As previously stated, the objectives were to look at existing systems first. Several commercially available portable delivery systems are already in existence, but are not necessarily perfectly designed for this application. They are packaged in various sizes and weights, in aerosol cans and pressurized canisters in portable, hand-carried cardboard boxes. Illustrations of several existing systems are shown in Appendix D.

Other companies proposed to design and develop a system to specifically fit the Army's requirements and needs. These systems were evaluated in case none of the existing systems was acceptable for this project. Company B developed line drawings of their delivery system concepts. Company E proposed a simple two-can system with no additional parts (such as hoses, nozzles, or mixing heads) needed to mix and dispense the foam. Illustrations of the proposed systems are also in Appendix D. Two companies did not express interest in modifying or developing smaller systems when their own did not completely suit this application. A disposable system which would be used once and thrown away was preferred by BRDEC. Delivery systems which had reusable or refillable containers were acceptable, but did not have a high priority because of the nature of the proposed scenario.

Criteria determined by BRDEC to be the most important in analyzing the delivery systems were weight of the total system, bulk, time required to prepare the system to dispense the foam, simplicity of use, and in the case of proposed systems, development time and production confidence. Simplicity of use refers to the level of complexity of the system. It was important to find a delivery method which was as mistake-proof as possible; this would help eliminate chances of the system not working properly in the field. The measurement involved is the number of steps required to ready the system for dispensing. This factor relates somewhat to the preparation time required to ready the system to apply the foam. A system which is not complex, but is simple to operate, is highly desirable. Table 5 below shows the prioritized list of criteria for delivery systems, with the weights reflecting the order of importance preferred by BRDEC.

TABLE 5. Delivery System Evaluation Criteria

CRITERIA	WEIGHT	EVALUATED IN TERMS OF
EXISTING SYSTEMS:		
Simplicity of use	35	Steps required to ready system
Preparation time	25	Seconds to prepare to dispense
Weight of system	20	Pounds per single delivery unit
Bulk	20	Size of system in cubic inches
Total	100	
PROPOSED SYSTEMS:		
Development time	25	Months to produce finished system
Simplicity of use	20	Steps required to ready system
Preparation time	20	Seconds to prepare to dispense
Weight of system	15	Pounds per single delivery unit
Bulk	15	Size of system in cubic inches
Production confidence	5	Percent chance of success
Total	100	

TOTAL SYSTEM ANALYSIS

There were other objectives or criteria which were considered, but did not contribute to the final list. These include long-term weathering effects, ease of disposal of the components and dispensers, and transportation constraints. The reasons these criteria were not used in the final analysis are:

- All products had the same level of performance for a determined objective
- Effects of the factors under consideration were not significant enough to have an adverse impact on the foam
- Factors under consideration were not a high priority for the countermine application
- Foam system would be used mainly in circumstances which made some criteria unimportant or irrelevant

The next step of the evaluation process is specifying the objective inputs shown in Table 6. Here, each factor related to a criterion is defined in terms of its specific measurement. These numbers come from product data sheets,

MSDS, company literature, and personal interviews with the product's company representatives. The data reflect the products and systems which the companies had available or had proposed at the time of this study. Modifications and new developments would change the specific numbers presented in Table 6. These are the final measurements of each product's characteristics and properties which are used to evaluate the candidates in LD. The candidates listed represent the surveyed companies' (A, B, C, D, E) products and/or systems. Performance characteristics clearly illustrate the differences between the products, and are used to justify final product decisions.

TABLE 6. Candidate Product Data

CRITERIA & MEASURE	CANDIDATES A	B	C	D	E
Cure time (minutes to spt wgt)	2	1	1	0.14	1
Compressive strength (psi)	25	20	10.4	25	25
Density (pcf)	2	0.5	1.75	1.4	2
Shelf life (years stored)	1	2	1.5	1	0.5
Component A hazards (NFPA rating)	6	4	4	4	8
Component B hazards (NFPA rating)	3	4	4	4	10
Development time (months)	0	4	0	0	3
Proposed Sys simp/use (steps)	0	2	0	0	5
Proposed Sys prep time (sec)	0	30	0	0	28
Proposed System weight (lbs)	0	0.5	0	0	0.5
Proposed System bulk (cu/in)	0	40	0	0	40
Production confidence (%)	0	96	0	0	95
Simplicity of use (steps)	5	0	7	5	0
Preparation time (seconds)	45	0	40	60	0
Weight (pounds per system)	20	0	3	25	0
Bulk (cubic inches per system)	200	0	50	200	0

The number of steps required to prepare the system to dispense foam was determined by carefully going through the preparation process with each of the five existing and proposed delivery systems. Operating instructions provided with the products also listed the steps required for use of the system. Some systems require removing the top or lid, and then pushing down on a spray nozzle to apply the foam;

this would be two steps. Other systems require mixing, shaking, or pouring. Each stroke required for mixing, each shake needed, and each pouring motion is counted as a separate step. Therefore, a system required to be mixed by pouring back and forth three times would have three steps for that part of the process, plus any other motions, such as pulling off the lid, and applying the foam.

Companies which did not plan any immediate modifications or developments received a zero (0) rating for those criteria dealing with proposed delivery systems, because the analysis of their products is based on their existing systems. If the company had any proposed system concepts, data was obtained from that company about the design plans and features so an objective measure could be applied. Production confidence levels were assigned after discussion with the companies themselves, and after viewing their facilities and evaluating their capabilities. Company B's measure for hazards is given as the maximum least-preferred level of the possible ratings because they do not yet have a rating in their present design phase. Company D also has that rating based on product information given by the company official who developed the foam. This information covered such areas as flammability, carcinogenic properties, and OSHA standards.

The most and least preferred levels for each measured criterion then had to be determined based on the requirements and desires of the project. The BRDEC subject-matter experts provided the specific numbers for this process. These subjective inputs to the analysis are shown in Table 7.

TABLE 7. Preferred Levels

Measure	Units	Least-Preferred Level	Most-Preferred Level
Cure time	min	4	0.5
Compressive	psi	10	25
Density	pcf	5	1.75
Shelf life	years	0.5	2
Hazards	rating	4	0
Development	mos	12	0
Simplicity	steps	5	1
Weight	lbs	3	0.5
Bulk	cu/in	100	40
Prep time	sec	120	30
Prod confd	%	85	100

These levels were used in LD to run the analysis, along with the preferences and weightings shown in Tables 4 and 5, supplied by the BRDEC subject-matter experts. The most and least preferred levels for the proposed systems are the same as listed above, since these are the preferred characteristics of the final system whether or not it is now in existence.

Figure 3 shows the structure of the complete goal tree built in LD. This illustrates the hierarchy of the analysis decisions, and shows the factors determined through the preceding process to be the most important. LD computes weights signifying the decision makers' preferences on each level of the tree. These weights are used to calculate the weights for the level until the overall goal of selecting the best complete foam system is reached.

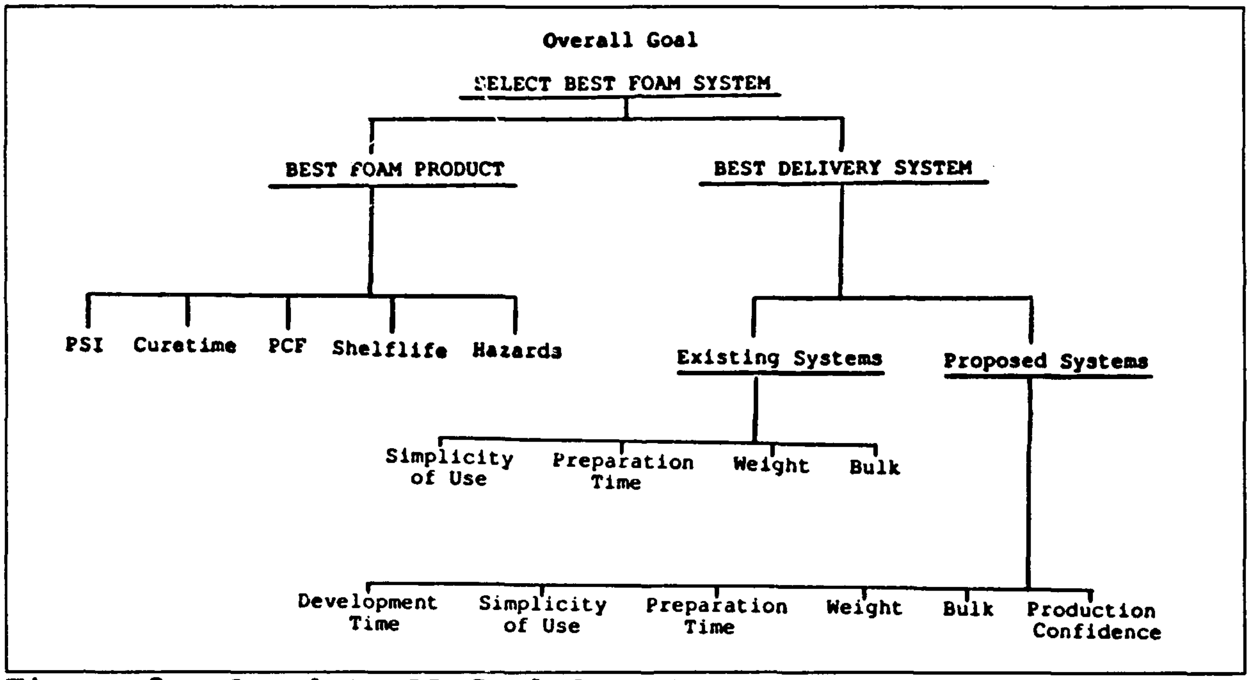


Figure 3. Complete LD Goal Structure

The goals of Existing Systems and Proposed Systems each have a weight of 0.50 in the LD analysis. This is because the two categories have to be compared equally against each other to give proper consideration to each in trying to determine the best overall delivery system. The goals of Best Foam Product and Best Delivery System also have equal

weights of 0.50 each because the overall goal of Best Foam System must include both factors - foam and delivery concept. A good foam product is just as important to this project as is a good delivery system. A complete foam system is the goal of this project.

LD ranks the alternative companies according to the total utility it has computed for each candidate. This ranking is the final result of the analysis process, and indicates which companies have the product with the most potential for meeting the Army requirements. Specific numerical rankings are shown in Table 8. This ranking shows that Company B was calculated by LD as having the most-suited product based on the information provided by that company, BRDEC, and CTI. Company E is next on the list of most-suited.

TABLE 8. LD Final Numerical Rankings

CANDIDATE	RANKING
Company B	2.129
Company E	2.058
Company D	1.662
Company C	1.560
Company A	1.544

To further illustrate the analytical and ranking process, each of the candidate companies are represented showing their placement on the bar charts shown in Figures 4 through 8 below. These charts are in final ranking order assigned to the candidate companies by the LD analysis to allow for better comparison. To interpret these charts, please note:

- Each criterion measured is represented by a bar. The height of the bar reflects the utility rating assigned by LD. If a bar is at the top of the chart, it has a utility of one (1), which means it meets or exceeds the most-preferred level. The width of the bar reflects the weight which was assigned to each measure by BRDEC.

- The last measure of OTHER and, therefore the last bar on the right side of the chart, represents the Component B Hazard and the Production Confidence measure combined. This is because the LD program can only represent 14 separate measure bars, and there were 16 total measures in this analysis.

- All of the capitalized measures reflect the foam product criteria. The remaining measures are the delivery system criteria.

- The measure definitions are read across, left to right, to correspond with the bars. For example, curing time, compressive strength, and density are the first three bars beginning on the left side of the chart; shelf life, Component A hazards and development time are the next three bars, etc.

- The overall utility computed by LD for each company is the total area of all of its bars. This is the numerical ranking for each company as shown above in Table 8. The numerical rankings exceed the level of 1 for utility because some measures were outside the ranges set for the most and least preferred levels.

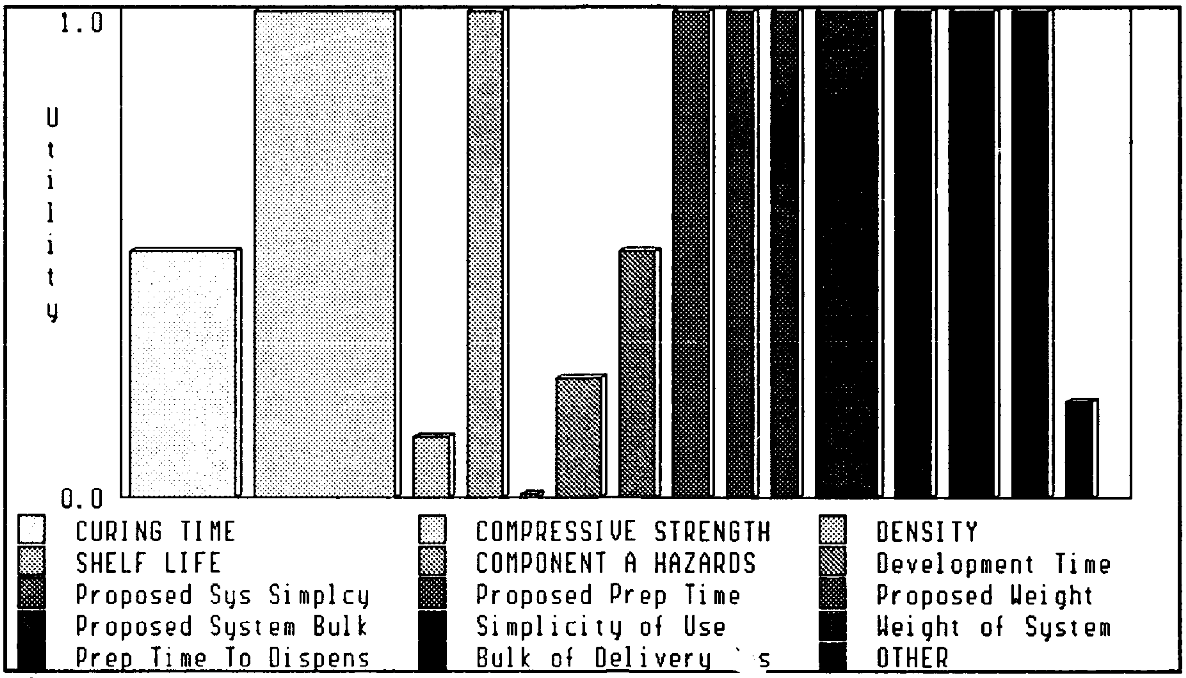


Figure 4. Company B Results

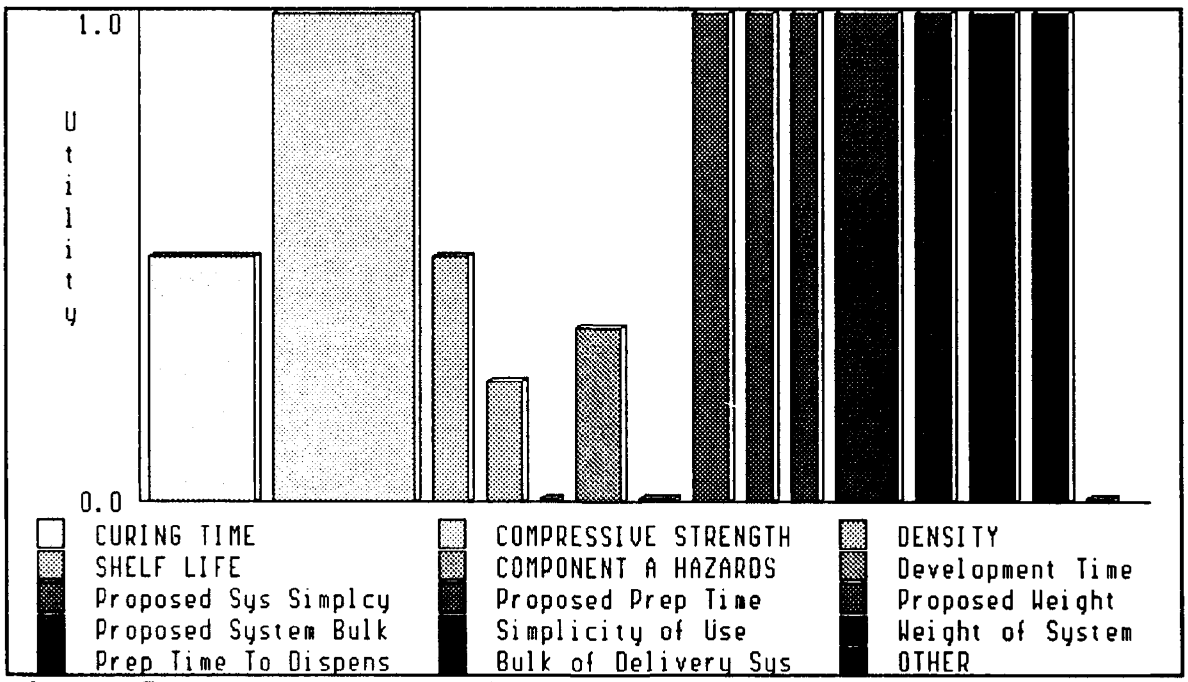


Figure 5. Company E Results

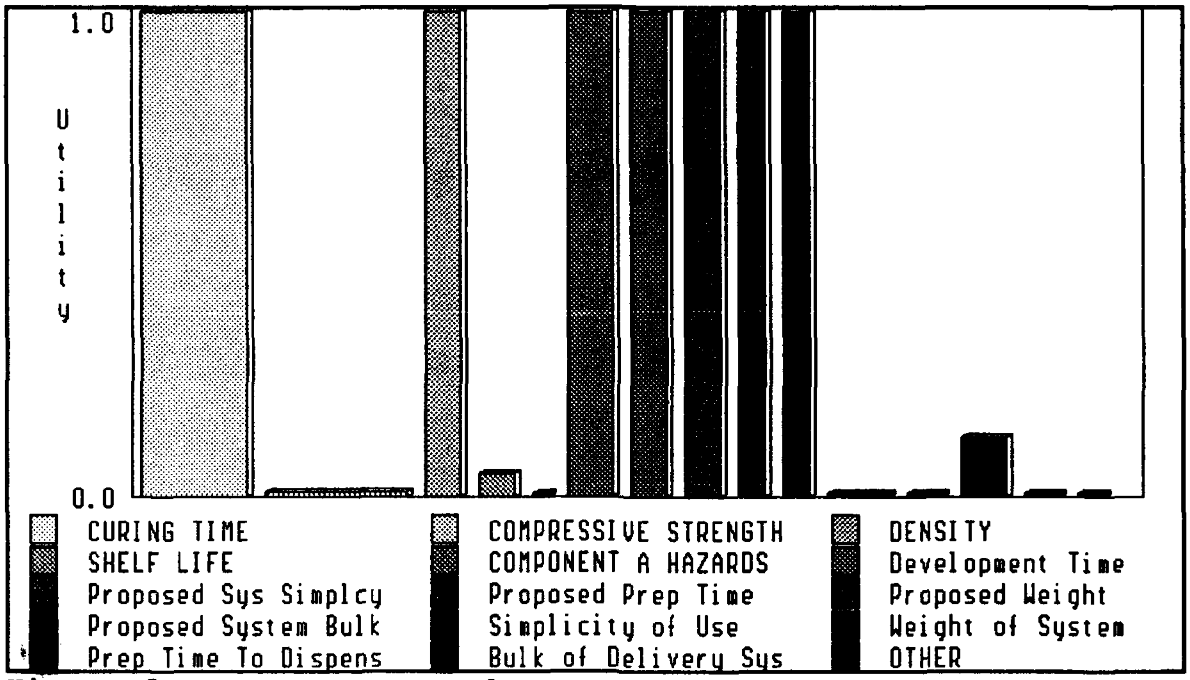


Figure 6. Company D Results

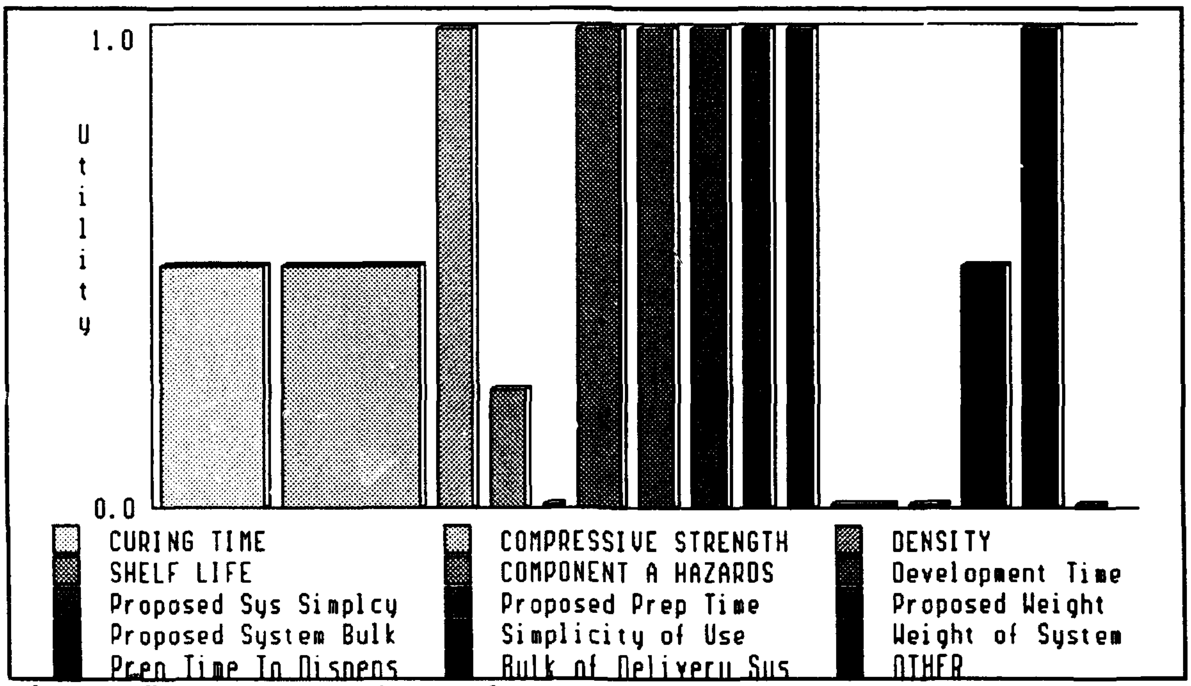


Figure 7. Company C Results

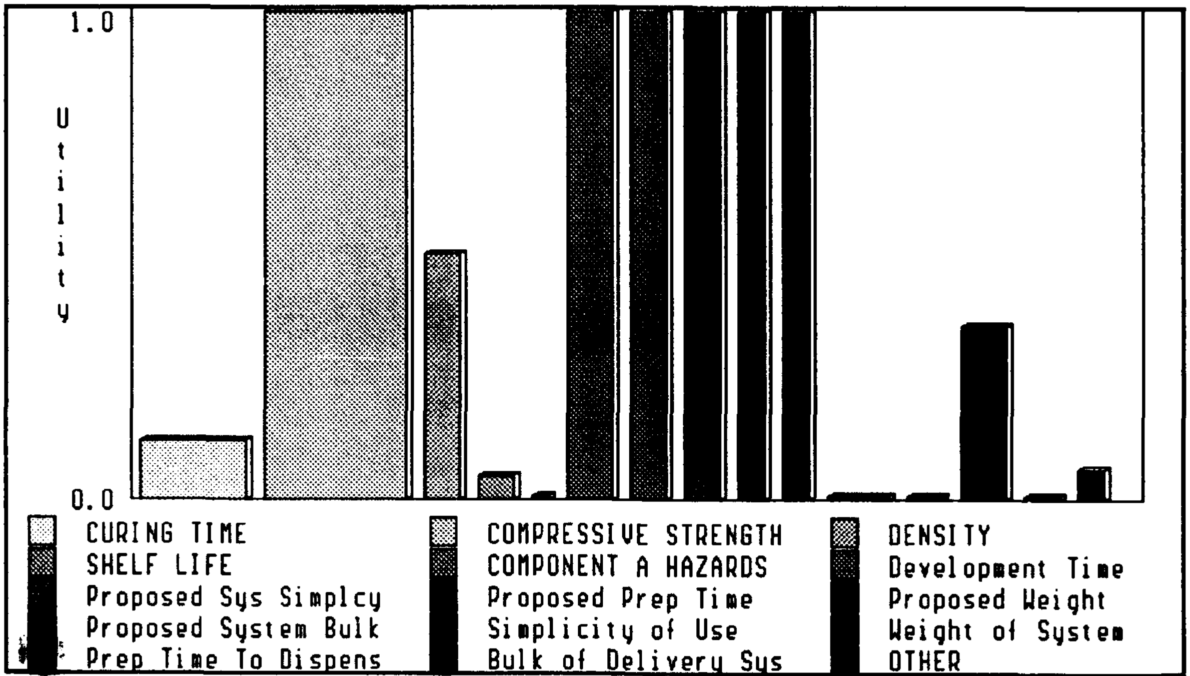


Figure 8. Company A Results

ANALYSIS CONCLUSIONS

The LD software assisted in accomplishing a useful and relevant analysis of the factors important to this study. The confidence level of the analysis depends on the accuracy of the data collected and entered. This was ensured by checking each entry and number assigned against the BRDEC requirements and preferences. The company data was checked against the product literature and with the company personnel. The analysis results accurately portray the products and systems addressed in this study.

The analysis performed indicates Company B and Company E have the products which have the most potential for neutralizing anti-personnel mines in the method proposed by this project. The bar charts show that these two companies came the closest to meeting the criteria levels preferred by the Army. The charts reflect the equal weight given to the combination of foam products and delivery systems. All of the companies were analyzed based on their existing and proposed systems. Companies B and E both propose to design a delivery system to closely fit the Army requirements. Company E has a foam currently in use which closely fits the project goals. The objective of finding a currently available delivery system to exactly match the project requirements was found to be unobtainable at this point in time. Further research, development, design, and testing will be needed; this has been shown through this analysis. Specific points about these companies' products and how they relate to the objectives are discussed in the following section - Recommendations.

RECOMMENDATIONS

As supported by the analysis, the products and dispensing systems proposed by Company B and Company E are recommended for further evaluation and testing of their capabilities to neutralize anti-personnel mines in a low intensity conflict environment. Each of the five companies are listed in the order of their final rankings with their products' strengths and limitations.

COMPANY B

COMPANY B PRODUCT/DISPENSING SYSTEM STRENGTHS: The proposed product's characteristics meets the most preferred levels determined by BRDEC as shown in Table 4. The product's structural foam meets the requirements for cure time, compressive strength, anticipated shelf life, and the desired density of the structural foam.

Company B proposes a small, compact, lightweight dispensing system, and will have the least amount of preparation steps to perform with the least amount of preparation time. This is reflected in the analysis. The proposed system is not restricted to one variation. Company B is currently investigating alternative systems, such as a microencapsulated product packaged as an aerosol can, and a belt-carried system. Company B currently contains the available resources necessary for development and manufacturing the proposed foam and system (i.e. facilities, key personnel, analytical and testing equipment). This was reflected in the production confidence measure in the analysis.

COMPANY B PRODUCT/DISPENSING SYSTEM LIMITATIONS: The proposed product and dispensing system are conceptual and still have yet to be developed and tested. There is a risk of developmental costs and delays in testing the product and dispensing system. The proposed structural foam's health hazard rating (an analytical factor) is unknown, and therefore was assigned the least preferred value for the analysis portion.

COMPANY E

COMPANY E PRODUCT/DISPENSING SYSTEM STRENGTHS: The product proposed by Company E is developed and is in use. The current product has a high compressive strength (38 psi) which is favorable but can be modified as desired. The two components which produce the structural foam remain at about the viscosity of water at all the anticipated operational temperature ranges without altering of the formula. No other product surveyed has this attribute. Two other strengths which were not used for objective evaluation in the analysis section are that the foam is not affected by water or moist substrates, and the foam does not require blowing agents such as Freon. The proposed delivery system is a concept similar to the packaging of the Meals-Ready-to-Eat (MREs), the military's current packaging of C-Rations. This would be a lightweight, compact, dispensing system in rugged plastic bags. The attributes of this type of packaging would be the lack of hardware (mixing heads, nozzles, valves, hoses, etc.). Without the hardware there is less chance of malfunctions or operational errors, increased ease of packaging and shipping, and less weight for the individual soldier to carry.

COMPANY E PRODUCT/DISPENSING SYSTEM LIMITATIONS: The foam product produced by Company E has the highest health hazard rating among the three products for which ratings were obtained. Company E also does not have a developed delivery system, and although the proposed dispensing system is simple, there is always a risk of developmental problems.

COMPANY D

COMPANY D PRODUCT/DISPENSING SYSTEM STRENGTHS: The product produced by Company D has an exceptionally fast cure time. The system preparation time and the compressive strength of the foam are within the limits of preferred levels as shown in Table 4.

COMPANY D PRODUCT/DISPENSING SYSTEM LIMITATIONS: The greatest concern with the product that Company D produces are the weight and bulk of the dispensing system. The proposed system exceeds the preferred levels for weight and bulk, as shown in Table 4. These limitations would restrict mobility of an individual who is deployed in a low intensity

conflict environment. The density of the foam does not meet the most preferred level. This proposed system also requires mechanical steps for preparation to operate the system. The use of valves, hoses, and switches leave open the risk of mechanical failures or operational errors. At the time this product was developed, there was not a requirement to obtain health hazard ratings for the A and B components, and they therefore are unknown. It was assigned the maximum least preferred level for this rating.

COMPANY C

COMPANY C PRODUCT/DISPENSING SYSTEM STRENGTHS: The product produced by Company C has good cure time and compressive strength. The product also has excellent foam density and meets the desired shelf life expectancy. The values are apparent in Tables 3 and 4. The dispensing system is also lightweight and compact, compared to other currently available dispensing methods.

COMPANY C PRODUCT/DISPENSING SYSTEM LIMITATIONS: The product proposed by Company C is less user-friendly in the preparation steps needed to operate the system. Preparational steps include activating the nozzle mechanism and turning valves and switches. Another limitation is that between uses the nozzle may need replacing due to hardening of the foam in the dispensing head. A subjective factor not used in the analysis is the operating temperature ranges for the products. Because this product uses Freon as a blowing agent, there is poor product performance at temperatures under 40 degrees Fahrenheit. Another relevant factor which was noted is that moist substrates and environments have an adverse effect on the quality of the final foam.

COMPANY A

COMPANY A PRODUCT/DISPENSING SYSTEM STRENGTHS: The product produced by Company A has excellent cure time, compressive strength, and the desired density for the structural foam. All of these characteristics enable this product to meet the requirements needed to defeat anti-personnel mines.

COMPANY A PRODUCT/DISPENSING SYSTEM LIMITATIONS: The greatest concern with the dispensing system that Company A produces is the weight and bulk of the system. Table 4 displays the Army's most preferred levels, and this dispensing system exceeds those levels in weight and bulk. This problem would definitely restrict an individual's mobility for use in a low intensity conflict environment. Another limitation is the preparation steps needed to operate the system. When using mechanical devices such as valves, switches, and nozzles, there is concern not only of mechanical failures but also operational errors.

As this study shows, there are definitely foam products and delivery systems currently available which, with slight modifications, could meet the system requirements. All of the five companies surveyed and analyzed have products with both strengths and limitations for this application. The deciding factor in choosing product(s) for further development will be which of these strengths and limitations are most important to the objective of neutralizing anti-personnel mines.

BIBLIOGRAPHY

BIBLIOGRAPHY

Abraham, Thomas and Pope, Gregory T., "Rapidly Solidified Materials." High Technology Business, pp. 28-32, November/December 1989.

Anderson, D., Sweeney, D., and Williams, T., Management Science: Quantitative Approaches to Decision Making, West Publishing Company, St. Paul, MN, 1988.

Arvidson, J.M., Sparks, L.L., and Guobang, C., Tensile, Compressive, and Shear Properties of a 64 kg/m3 Polyurethane Foam at Low Temperatures, NBSIR-83-1684, National Bureau of Standards, Boulder, CO, February 1983.

Bauman', G., Engineering Plastics and Their Commercial Developments, editors: The American Chemical Society. Chapter 4 - Thermoplastic-Thermoset, Washington, D.C., 1969.

Chamberlain, Gary, "New Design Battleground: Auto Interiors (Plastics)," Design News, pp. 56-64, January 22, 1990.

Chung, F.T.H., and Hudgins, D.A., Development of an Engineering Methodology for Applying Foam Technology, NIPER-374, National Institute for Petroleum and Energy Research Bartlesville, Oklahoma, May 1989.

Churbuck, David, "The Plastic House", Forbes, pp. 162-163, February 5, 1990.

Cromie, William J., "Building Homes with Foam", The Futurist, p. 52, March/April 1990.

Driver, Walter E., Plastics Chemistry & Technology, Chapter 7-Foams, Chapter 11-Processing & Fabrication, Van Nostrand Reinhold Company, New York, 1979.

Engineer Field Data, Army FM 5-34, HQ Department of the Army, Washington DC, 1987.

Fizette, Paul, "Phenolic Foam Insulation", Progressive Builder, pp. 21-24, January 1987.

Gilmore, V. Elaine, "Foam-Block House", Popular Science, pp. 52-54, 93, December 1987.

Gilmore, V. Elaine, "Reinventing the House", Popular Science, pp. 102-112, March 1990.

Harvey, J.A., Butler, J.M., and Chartoff, R.P., Development of Polyisocyanurate Pour Foam Formulation for Space Shuttle External Tank Thermal Protection System, NASA-CR-183511, Research Institute, University of Dayton, Ohio, August 1988.

Hollaway, Leonard, Glass Reinforced Plastics in Construction: Engineering Aspects, Chapter 6, John Wiley & Sons, New York, 1978.

Howard, Michael J., editor, Foams: Desk Top Data Bank, Edition 2, The International Plastics Selector, Inc., San Diego, CA, 1980.

Langdon, William K., Movable Insulation, Chapter 2, Chapter 4, Rodale Press, Emmaus, PA, 1980.

Levy, Sidney and DuBois, J. Harry, Plastics Product Design Engineering Handbook, Van Nostrand Reinhold Company, New York, 1977.

Light Forces Sapper Countermine Guide for Low to Mid Intensity Conflict, BRDEC Pamphlet 350-3, Belvoir Research, Development, and Engineering Center, Countermine Systems Directorate, Fort Belvoir, VA, March 1990.

LOGICAL DECISION, Logical Decisions Software, Point Richmond, CA, 1989.

Lubin, George, editor, Handbook of Composites, Van Nostrand Reinhold Company, New York, 1982.

Marsden, James N., "Defeat of Tactical Mine Fields", National Defense, pp. 127-129, September-October 1975.

Marshall, M.D., Evaluating Rigid Foams for Construction and Repairing Mine Stoppings, B of M-OFR-40-85, MSA Research Corporation, Evans City, PA, October 1984.

O'Sullivan, Dermot, "PET Bottles Recycled Into Insulation Foam", Chemical and Engineering News, pp. 25-26, February 12, 1990.

Patton, William J., Plastics Technology: Theory, Design & Manufacture, Chapter 7-Plastic Foams, Reston Publishing Company, Reston, VA, 1976.

Patton, W.J., Materials in Industry, Chapter 15-Foams, Prentice-Hall, Englewood Cliffs, NJ, 1976.

Pearson, Clifford A., "The Sky's the Limit", Architectural Record, pp. 134-135, October 1989.

Radford, K.J., Modern Managerial Decision Making, pp. 135-147, Reston Publishing Company, Reston, VA, 1981.

Smith, Alvin, Investigation of Rapidly Deployable Plastic Foam Systems, Volume I: System Development, CERL-TR-M-272, U.S. Army Construction Engineering Research Laboratory, Champaign, IL, October 1979.

Smith, A., Wang, S.S., and Kuo, A.Y., Investigation of Rapidly Deployable Plastic Foam Systems, Volume II: Nonlinear Deformation and Local Buckling of Kevlar Fabric/Polyurethane Foam Composites, CERL-TR-M-272, U.S. Army Construction Engineering Research Laboratory, Champaign, IL, October 1979.

Sloan, C.E.E., Mine Warfare on Land, Brassey's Defence Publishers, London, England, 1986.

Tortolano, F.W., "Workhorse Plastics", Design News, pp. 63-70, May 7, 1990.

Zhang, J. and Ashby, M.F., Energy Absorption of Foams and Honeycombs, CUED/C-MATS/TR-159, Engineering Department, Cambridge University, England, May 1989.

APPENDIX A

SURVEY QUESTIONNAIRE

SURVEY QUESTIONS

DEPLOYMENT CHARACTERISTICS

1. Briefly describe your company's methods; i.e. structural foams or chemicals. Include items such as amounts required to be effective, length of effectiveness, composition of product, and how it works (catalysts, corrosives, bonding, binding agents, etc.).

2. Define the elapsed time for the product to perform its mission, such as hardening/setting time, chemical reaction time, etc.

3. State the duration of the product's effectiveness (hours, days, weeks, indefinitely).

4. What is the product's compressive strength under stress (pounds/square-inch)?

5. Will your product's effectiveness be altered by marking or coloring agents (paint, chalk, visible coatings, etc)?

6. Can your product be manufactured for nighttime visability without changing its effectiveness?

7. State the number of applications per each dispensing unit based on 1 square foot per application.

8. Can your product be applied to different materials such as (plastics, aluminum, iron, wiring mechanisms, soil, etc.)? Describe the resulting interactions such as bonding characteristics and chemical reactions.

LOGISTICAL CHARACTERISTICS AND REQUIREMENTS

1. Does your product need accessory equipment for its application? Explain how the dispensing system works.

2. How is your product packaged?

3. Is your product and its dispensing unit/system lightweight and compact; can (1) person carry and deploy it? If not, could it be designed to be handled by one person?

4. Is your product "ready to use" (simplicity of application)?

5. Is your product/product container limited by storage constraints (flammability of product/product container, storage in pressurized environment, withstands shock of impact, etc.)?

6. What shelf life do you expect of your product? Do environmental conditions affect shelf life?

7. Are your product dispensing units/systems reusable?

ENVIRONMENTAL CHARACTERISTICS

1. What is the environmental impact of your product once deployed? (For example, is your product biodegradable; can your product be neutralized/cleaned up after its application?

2. Is your product resilient to environmental elements, such as heavy rain, high humidity, gusty wind conditions, sandy environments, and cold climates?

3. What materials are needed for "cleaning up" your product in the event of inadvertent applications, spills, training exercises, or other circumstances?

4. Does your product(s) require special handling considerations? Will the user need protective gear during application?

5. Would this product or system be effective in an environment which is watery, such as a swamp or marsh? Expain how it would work under these conditions.

GENERAL QUESTIONS

1. Is it feasible for your company to develop a product(s) which meets the survey requirements?

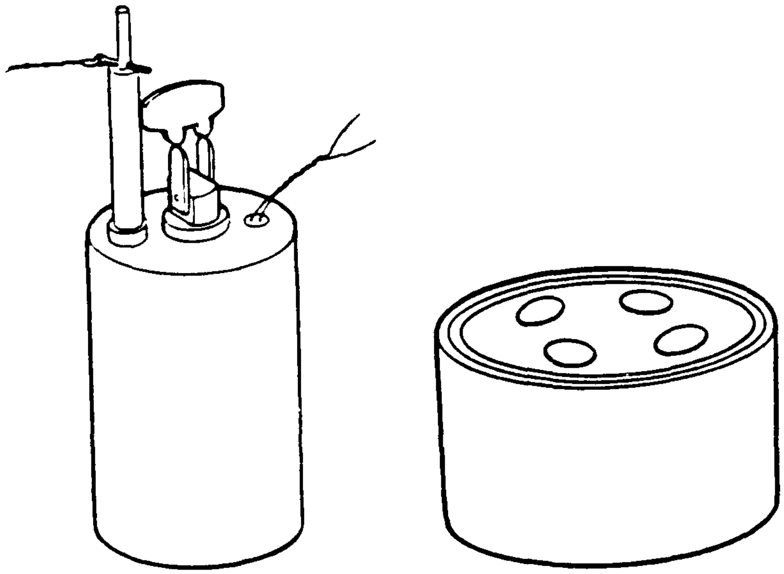
2. Does your company have an existing product which meets the survey requirements?

3. If your company does have an existing product(s), has it been tested? Will the test data be available if your product is being considered as a candidate for further analysis? Test data should include specifics such as reactions to foreign materials, stress, weather conditions, etc.

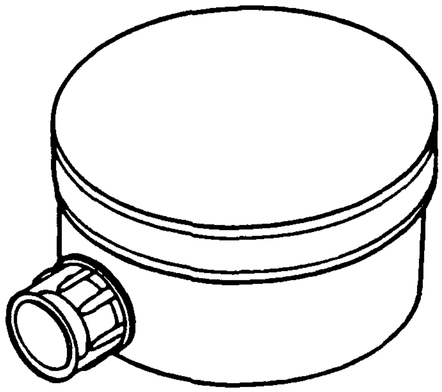
APPENDIX B

ANTI-PERSONNEL MINE ILLUSTRATIONS

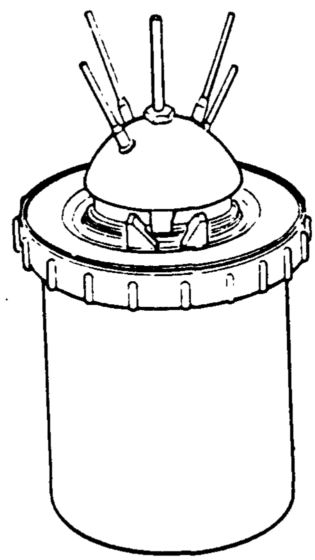
Anti-Personnel (AP) Mines
Which Could Be Effectively Neutralized
Using the Products and Systems Recommended in this Study



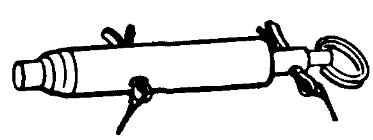
Typical Tripwire AP Mines



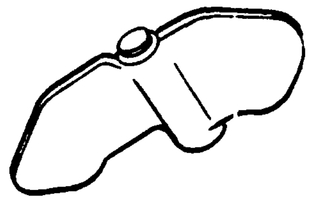
Typical Pressure-Plate AP Mine



Typical Tilt-Rod AP Mine

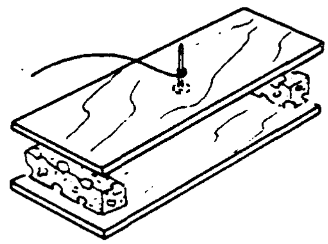


Typical Pull Firing Pin Device

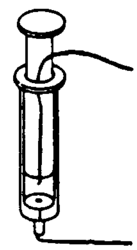


Pressure-Sensitive Plastic-Cased Mine

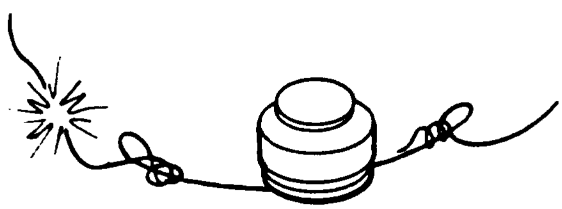
Two Pieces of Wood or Metal



Hypodermic Syringe



Button Switch (Doorbell)



Typical Anti-Disturbance and Booby-Trap Devices

APPENDIX C

FORMULAS USED IN LOGICAL DECISION SOFTWARE ANALYSIS

Linear Single-Measure Utility Function:

$$U(X) = a + bX$$

Where: U is the calculated utility (measure of desirability)
a and b are computed scaling constants
X is a level for the measure

Exponential Single-Measure Utility Function:

$$U(X) = a + (be^{(-cX)})$$

Where: U is the calculated utility
a, b, and c are computed scaling constants
e is the mathematical constant 2.718...

Additive Formula for Multiple-Measure Utility Function:

Used when weights (small k's) sum to 1.0

$$U_g(X) = k_1U_1(X) + k_2U_2(X) + \ldots + k_nU_n(X)$$

Where: $U_g(X)$ = is the utility of alternative X for the group g
$U_i(X)$ = the utility of alternative X for the ith member of g
k_i = the scaling constant small k for the ith member of g

Multiplicative Formula for Multiple-Measure Utility Function:

Used when weights do not sum to 1.0

$$U_g(X) = ((1 + Kk_1U_1(X))(1 + Kk_2U_2(X))\ldots(1 + Kk_nU_n(X)) - 1)/K$$

Where: $U_g(X)$ = the utility of alternative X for group g
K = the scaling constant big K for g
k_i = the scaling constant small k for member i of g
$U_i(X)$ = the utility of alternative X for member i

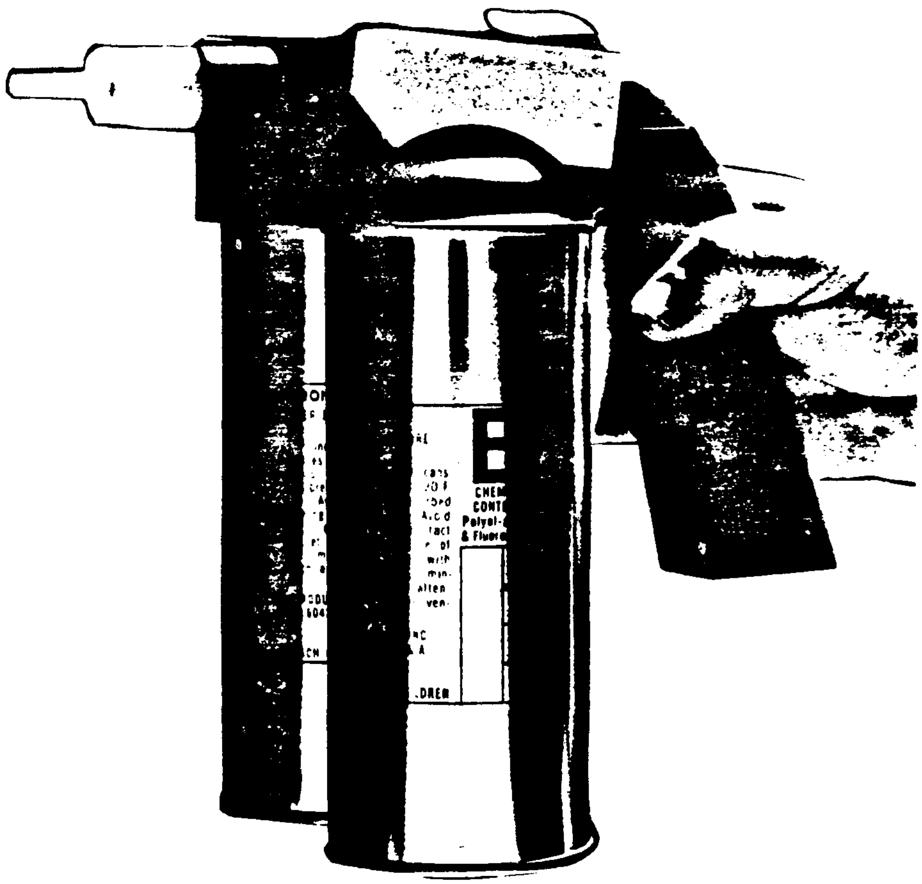
Source: Logical Decision software manual, Logical Decisions, Point Richmond, CA, 1989.

APPENDIX D

ILLUSTRATIONS OF DELIVERY SYSTEMS

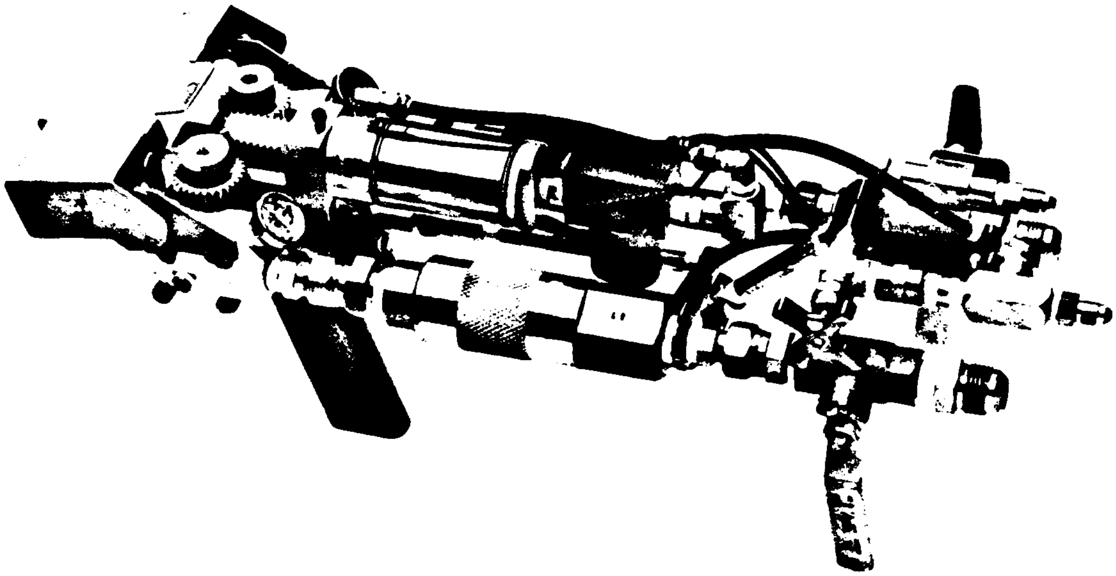
including
Existing Systems and Proposed Concepts

EXISTING TECHNOLOGY

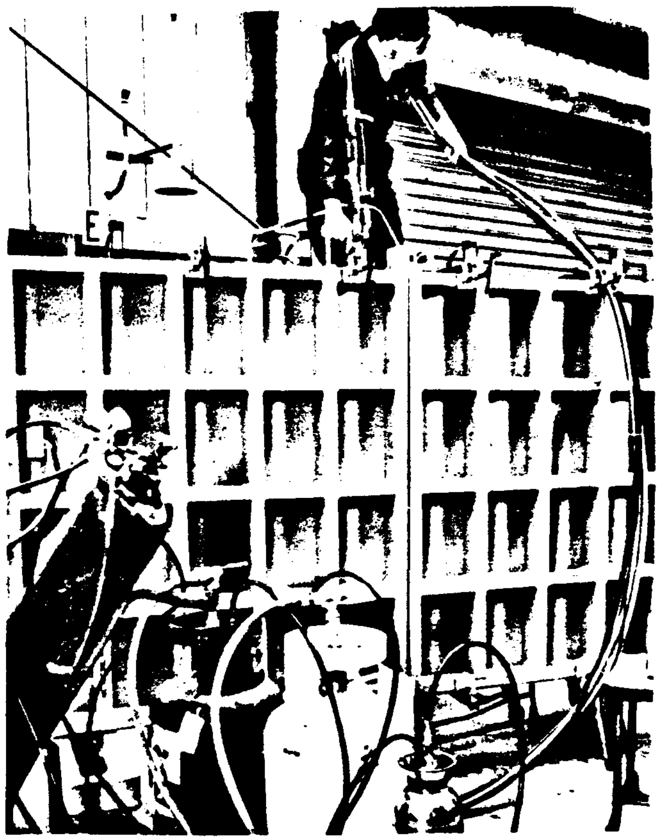


PORTABLE TWO-COMPONENT DELIVERY SYSTEM

EXISTING TECHNOLOGY

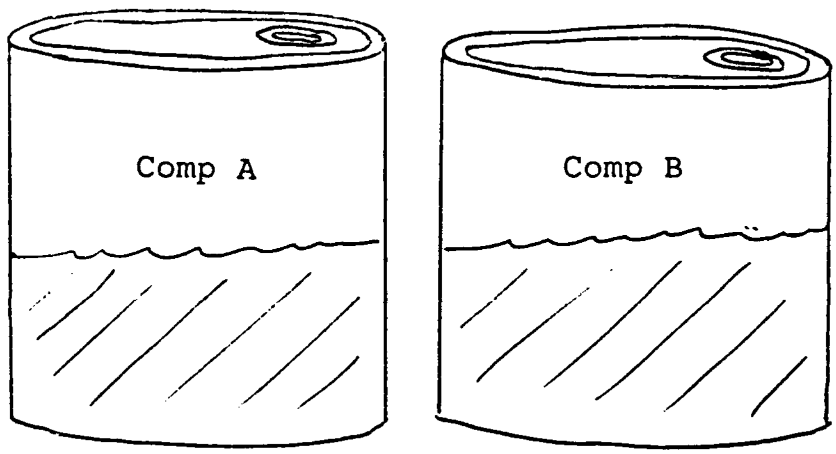


PORTABLE HAND-HELD DISPENSING GUN



MEDIUM-SIZED SYSTEM IN USE

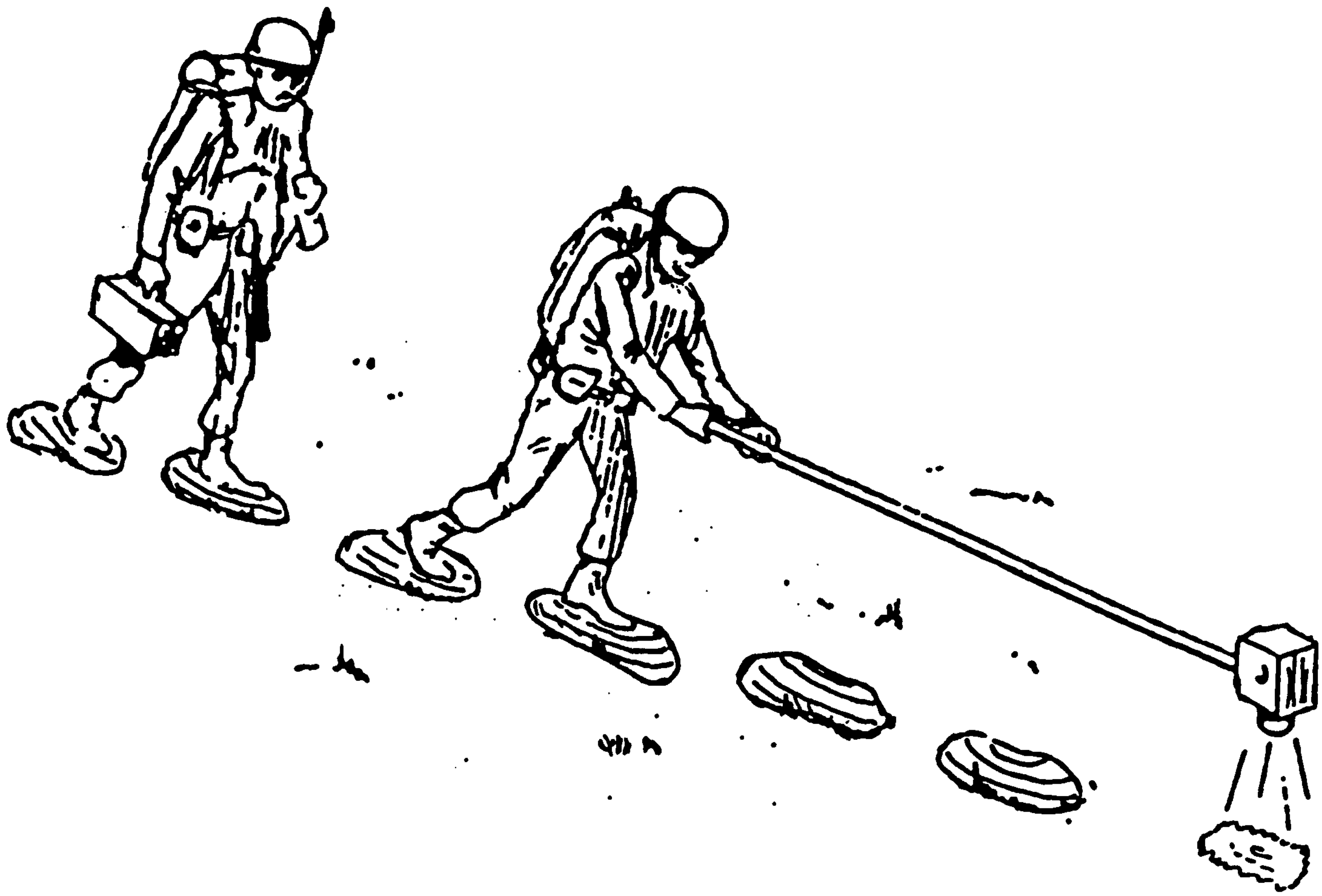
PROPOSED CONCEPTS



TWO COMPONENT POUR-IN-PLACE SYSTEM

Two Small Body-Hugging Cans or Plastic Pouches
Similar to Meals-Ready-To-Eat (MRE) pouches

About 70 grams in each container; expands to about 30 times in volume when mixed and poured over mine



BACKPACK FOAM DISPENSER

With Extension Arm for Applying Foam in Advance of Personnel

APPENDIX E

This appendix is a separate document and is available to authorized readers only.